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In Cooperation with the
Illinois, Oklahoma, and Missouri Agricultural Experiment Stations

HYDROLOGIC DESIGN OF FARM PONDS AND RATES OF RUNOFF FOR DESIGN OF CONSERVATION STRUCTURES IN THE CLAYPAN PRAIRIES

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Division of Drainage and Water Control

MAY 1945

FOREWORD

This publication is one of a series containing information for the hydrologic design of farm ponds and of other conservation strucutres and practices in important agricultural areas where hydrologic studies have been made by the Soil Conservation Service. The information and procedures contained in these publications are based on runoff, rainfall, and other hydrologic data obtained from the runoff studies and from other research projects of the Service conducted in co-operation with State Agricultural Experiment Stations. United States Weather Bureau records of precipitation and published and unpublished records of evaporation; published and unpublished records of stream flow of the United States Geological Survey; and available records from other sources are utilized in the preparation of these technical publications.

Basic hydrologic data for the Claypan Prairies, particularly records of runoff from small watersheds, are still limited both as to range in watershed size and as to length of record. More definite information is needed on relation of rates and amounts of runoff to size of drainage area and on other factors such as seepage and silting. Runoff studies must be continued over a period long enough to verify the value of rates and amounts of runoff for various recurrence intervals. Field studies of evaporation from small reservoirs must be conducted to verify the values used in this report. In view of the above, the information contained in this publication must be considered tentative and subject to revision until such time as the deficiencies in basic hydrologic data are eliminated.

Simplified instructions based on this publication are made available for use in planning small farm ponds, the cost of which will not exceed $500. The more complete procedure outlined in this report should be followed in planning costlier developments and smaller ponds in which only minor fluctuations in the depth of water can be permitted.

M. L. Nichols
Chief of Research

ACKNOWLEDGMENTS

The establishment of the runoff studies and the collection of the records utilized in the preparation of this report involved the work of the authors and other members of the Division of Drainage and Water Control, Soil Conservation Service - Research. The construction of the measuring devices and field observations for the Edwardsville, Illinois, and Muskogee, Oklahoma studies were carried out by the Operations personnel assigned to this work by Regions 3 and 4 of the Service. Records for the studies at Muskogee, Oklahoma, and McCredie, Missouri, were furnished by V. D. Young and D. D. Smith, project supervisors, Soil Conservation Service - Research. In delineating the areas of application and determining the required amounts of water used in the illustrative examples, the authors had the benefit of discussions with Operations technicians of the Washington and regional offices of the Service. The field studies and the analysis of the records were carried out under cooperative project agreements and working plans approved by the Agricultural Experiment Stations of Illinois, Missouri, and Oklahoma.

The manuscript of this report was reviewed by Mr. L. A. Jones[1] and by the technical staffs of the Missouri, Illinois, and Oklahoma Agricultural Experiment Stations and of regional offices of Regions 3, 4, and 5 of the Soil Conservation Service. The authors are indebted to the reviewers for their valuable suggestions and constructive criticisms. The contribution of Mr. W. D. Potter[2] to the simplified procedure developed at the suggestion of Mr. Jones and others is more fully acknowledged on page 19. Miss Bernadette Reid and others performed and checked the many detailed computations and typed the manuscript. Their painstaking efforts are gratefully acknowledged.

The exacting and important task of typing the final draft and of assembling and arranging the material was performed by Miss Georgie A. Keller whose assistance is gratefully acknowledged.

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SYNOPSIS

This report consists of two parts: *Part I* deals with the hydrologic design of farm ponds; *Part II* gives rates of runoff for use in the design of conservation structures on small agricultural areas.

The values and recommendations are based on the authors' analysis and interpretations of hydrologic records obtained by the Soil Conservation Service from research projects conducted in co-operation with the Agricultural Experiment Stations of Illinois, Missouri, and Oklahoma, and of related published and unpublished records obtained from other sources.

The principles involved in the hydrologic design of farm ponds are discussed briefly. Quantitative relations are presented in the form of equations and formulas. Values of evaporation minus precipitation $E - P$ and of surface runoff R for use in the hydrologic design of farm ponds are given in *table 1.* The use of these values in the planning of large farm ponds is illustrated in numerical examples. The examples must be carefully studied to gain a working knowledge of the procedures outlined in this report. The areas of application, the 4 zones in which different values of $E - P$ and R are to be used, and the factors to be applied to the basic rates of runoff are shown on a map, *(fig. 1).*

The meaning of "recurrence interval" which is basic to the proper use of the information is strongly emphasized and explained on *page 6.*

Because the hydrologic design of farm ponds and conservation structures involves estimates of future occurrences, and because of the lack of sufficient hydrologic records, the authors felt compelled to be conservative in arriving at the values presented in this report. For this reason, no "factors of safety" need be applied in using the curves and values given herein, particularly the values of $E - P$ and R.

No information is included on the structural design and hydraulic characteristics of grassed channels, terraces, spillways, and other structures used in disposal of excess runoff, or of appurtenances of farm ponds. Reference is made, however, to published reports of the Soil Conservation Service and to other publications dealing with these subjects.

The results of the analysis presented in this report indicate that dependable supplies of water sufficient for livestock and other uses on the farm, including supplemental irrigation, can be readily secured by means of farm ponds of reasonable depth on drainage areas (less than 100 ac.). The rather small differences in rates of runoff to be used in the design of various structures on pasture and cultivated watersheds in the Claypan Prairies are no doubt due to the very limited capacity of the soils to absorb and retain the large amounts of intense rainfall which may be *expected* once in 25 or even once in 10 years.

SOURCES OF DATA

The Claypan Prairies in Illinois and Indiana; Iowa, Missouri, Kansas, and Oklahoma, *(fig. 1)*, are the areas in which the data included in this publication are applicable. Within these areas, records of runoff applicable to the design of conservation structures and practices for small drainage basins are limited to those obtained by the Soil Conservation Service near Edwardsville, Illinois; Muskogee, Oklahoma; and McCredie, Missouri. The records from these studies include:

(a) Runoff, rainfall, temperature, relative humidity, and cover and tillage records for 6 years (1938-43) for 4 watersheds located north of Edwardsville, Illinois. These 4 watersheds include a 12.5-acre terraced and cultivated area; a 27-acre area which was in mixed crops for 3 years (1938-40) and alfalfa for 3 years (1941-43); a 50-acre pastured area; and a 290-acre mixed-crop area (1/2 open and wooded pasture, 1/4 alfalfa, and 1/4 cultivated).

(b) Runoff, rainfall, temperature, relative humidity, and cover and tillage records for a 5-year period (1939-43) from 4 watersheds near Muskogee, Oklahoma. These 4 watersheds include a 14.5-acre strip-cropped area; a 22-acre cultivated area; a 25-acre pastured area; and a 65-acre terraced and cultivated area.

(c) Rainfall and runoff for 3 years (1941-43) on a 153-acre pastured area at the Soil Conservation Experiment Station near McCredie, Missouri.

Records of evaporation from United States Weather Bureau class A pans are available for 6 to 8 years at a number of locations within or near the Claypan Prairies, one station having an 11-year record. "Evaporation from Lakes and Reservoirs," by the Minnesota Resources Commission, contains mean monthly evaporation and annual evaporation computed by Adolph Meyer's formula for 50 years at several locations within the Claypan Prairies.

United States Weather Bureau records of precipitation for 50 years and longer are available from a number of stations.

Short records of runoff for Canteen Creek at Caseyville, Illinois, with a drainage area of 22.5 square miles (Oct. 1939-43), for Indian Creek at Wanda, Illinois, with an area of 37 square miles (Oct. 1940-43), and for Bay Creek at Pittsfield, Illinois, having an area of 39.8 square miles (Oct. 1939-43) were obtained by the United States Geological Survey.

The runoff and evaporation records are far too meager to permit a complete analysis on which to base final recommendations for design. However, in view of the urgent need for hydrologic data in connection with the rapidly expanding conservation programs, it is deemed advisable to make available the best estimates possible from the records obtained thus far. The recommendations contained in this publication must be considered tentative, and subject to revision when additional records have been obtained and improved methods of analysis have been devised. In the present status of the science of hydrology, rigorous proofs are seldom possible. Some of the recommendations must, therefore, be based on the judgment of the authors guided by experience and knowledge of hydrologic phenomena. For this reason, and because this report is intended primarily as a guide in design of conservation structures and practices, no attempt is made to discuss the procedures followed in arriving at suggested rates of runoff and other data. The brief discussion is devoted mainly to the methods to be followed in utilizing the results of the analyses in the hydrologic design and planning of farm and ranch ponds and of other conservation structures and practices.

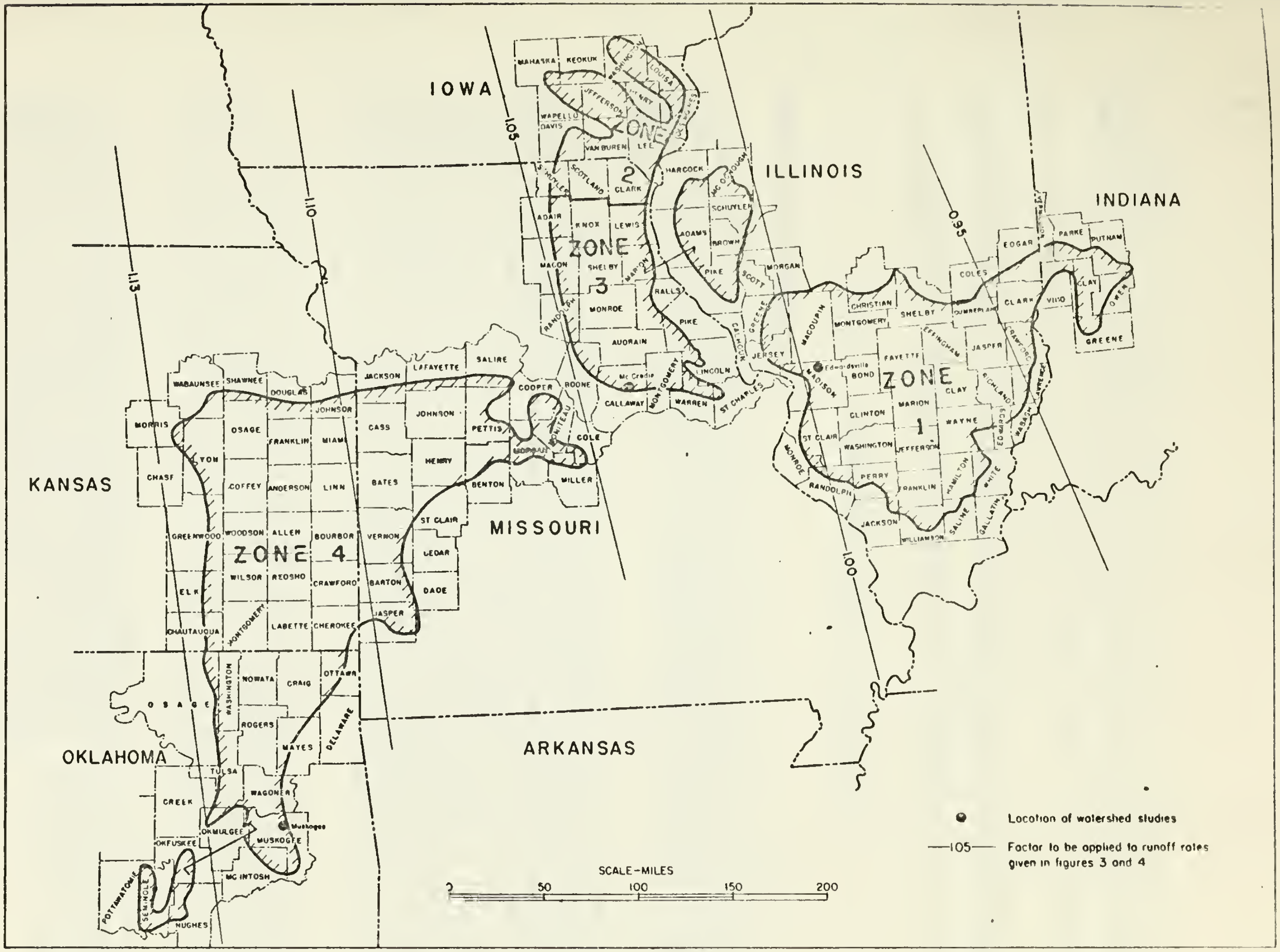


Figure 1 - Claypan prairies

The design and planning of conservation structures and practices in the Claypan Prairies, which must be based on adequate hydrologic data, such as rates and amounts of runoff, evaporation, precipitation, etc., fall into the following general classes:

1. Farm ponds used to furnish water for stock, domestic use, fish production, supplemental irrigation, recreation, and other purposes.

2. Intercepting ditches, drainage-type terraces, grassed waterways, and other channels for conveyance of excess water from cultivated, grassed, and other areas.

3. Spillways for gully-control structures, soil-saving dams, and for farm ponds; such spillways include drop inlets, tile drains, notches, and flumes.

PART I. HYDROLOGIC DESIGN OF FARM PONDS

General Considerations:

Farm ponds have an important place in a balanced agricultural program for the Claypan Prairies. Such ponds are commonly used in these areas to provide water for livestock. The recurring droughts in the past decade and the present trend toward more pastures have resulted in a greatly increased interest in farm ponds on the part of farmers, soil-conservation districts, and other agricultural agencies in the Claypan Prairies.

Precipitation, evaporation, and soil characteristics are such as to make the use of farm ponds highly advantageous and hydrologically feasible. The shallow soils are underlain by nearly impervious subsoils, so large amounts of surface runoff are obtainable from cultivated land, and considerable amounts from areas in mixed crops and even from moderately grazed pastures. Evaporation during the growing season is high, and for critical periods exceeds the precipitation. It is, however, not so great as to make impractical the use of relatively shallow ponds of considerable capacity. These conditions indicate the feasibility of using ponds for fish production, recreation, fire protection, orchard spraying, and for supplemental irrigation of truck gardens, small orchards, and even small acreages of field crops. Farm ponds also offer a practical means of disposal of excess runoff from drainage-type terraces. Large farm ponds may under certain conditions be effective in flood-flow retardation on small streams, when large temporary storage is provided above spillway elevation.

Seepage, which in other regions may often make construction of farm ponds infeasible, is not serious in the Claypan Prairies. With reasonable care in selecting the site and in constructing the dam and/or excavating the site, seepage can be practically eliminated. The fact that adequate amounts of surface runoff can be expected even from good pastures makes it practicable to reduce greatly the sedimentation hazard by keeping the area adjoining the pond in pasture or, in case of small ponds, by keeping the entire drainage area in pasture.

In the Claypan Prairies, as elsewhere, the feasibility of individual reservoirs and their cost are determined by the characteristics of the site and by the hydrologic factors involved. The complexity of the relations makes it difficult to present them clearly and concisely except by means of numerical examples. The users of this publication are urged to study these examples carefully if they wish to acquire a working knowledge of the basic data and procedures outlined in this report.

Definition of a Dependable Water Supply:-

The primary consideration in a farm pond designed to furnish required amounts of usable water is the dependability of the water supply. What constitutes a "dependable supply," or stated in other words, how often can the amount of usable water be allowed to fall below the required minimum, will depend on the purpose of the pond, the cost of construction, the economic value of water, and the expectancies of various amounts of precipitation, runoff, and evaporation in the region. With these considerations in mind, *a dependable supply in the Claypan Prairies may, depending on the cost and purpose of the development, be defined as one which on the average will not fail more frequently than once in 5, 10, or 25 years; or a minimum supply which can be depended upon 80, 90, or 96 percent of the time.* In arriving at the required drainage area and the allowable dimensions of the pond, both of which determine the available supply, it is necessary, therefore, to balance against the total amount required for use the *total available supply* which can be expected to be equaled or exceeded 80, 90, or 96 percent of the time. This must be done for several critical seasons because the balance may be favorable for 1 critical season but may prove unfavorable for 2 or more such seasons.

We have so far discussed one phase of dependability. There is another phase which must be considered, namely, the probability of the pond filling within a reasonable time after completion. A deep pond with a given surface area on a relatively small watershed may furnish a dependable supply after it once filled, but the drainage area may be so small that exceptionally heavy precipitation and runoff would be required to fill the pond while it is supplying the required amount of water. If the occurrence of such heavy precipitation is too rare, several years may elapse before the reservoir is filled. Obviously, there is an economic limit for the period to be allowed for filling the pond. The length of this period is determined by economic considerations based largely on the value of water and by the seasonal distribution of rainfall, runoff, and evaporation. *Conditions in the Claypan Prairies indicate that a period including 2 growing seasons after completion of the pond--17 months if the pond is completed in the late spring or early summer--would be a reasonable period to allow for its filling. A longer period including 3 growing seasons may be allowed in special cases.*

In arriving at the drainage area required to fill a given pond within this period, the total supply for 17 or 29 months beginning in May must be balanced against the total volume of the reservoir at spillway elevation plus the amount of water which will be used during the period. In arriving at the supply, in this case, it is not necessary to consider amounts which may be expected to be equaled or exceeded as much as 96 or even 80 percent of the time. *In the Claypan Prairies, amounts which may be expected to be equaled or exceeded 75 percent of the time are considered adequate in determining the probability of filling the pond within a reasonable period after completion.*

At the present time the tendency is toward letting the construction of ponds on contract. This means that ponds may be completed in the late spring, early summer, or at any time during the year when conditions are suitable for construction. Small ponds, however, may in some cases be constructed by the farmers themselves in which case they would usually be completed in the early fall. The effect of using in all cases a period which includes 2 growing seasons would be that of an added factor of safety for cases when the ponds are completed at the end of the growing season because in such cases the actual period available for filling would be 24 instead of 17 months. In view of the uncertainty as to the time of completion, it is not deemed advisable to use periods which include only 1 growing season (12 or 19 months).

If a 12-month period (beginning in October) is allowed, drainage areas considerably larger than necessary to *maintain* a dependable supply will be required in all parts of the Claypan Prairies. Using a 18-month period (beginning in Oct.) will not greatly change the drainage areas in some parts, while in others, larger drainage areas will have to be used than are necessary to maintain a dependable supply. The types of spillways used on small ponds and the desirability of keeping the entire drainage area within the individual farm whenever possible make it important to insure that the drainage area is not larger than necessary to fill the pond within a reasonable period after completion and to maintain a dependable supply after filling.

Important Note:

It is well to emphasize the meaning of the expectancies mentioned in the foregoing discussion. When we say that a given amount of water for a critical period can be expected to be equaled or exceeded 96 percent of the time, on an annual basis, or 24 out of 25 years, we do not mean that 24 years will necessarily elapse before a smaller amount will occur. This may not happen at all, or it may happen more than once and at any time during a 24-year period. We mean that over a long period, say 100 years, lesser amounts will occur on the average not more than once in 25 years. The same applies to 75, 80, or 90 percent of the time. It is important that this concept be clearly understood by both technicians and clients when technical assistance in the design of farm ponds is rendered.

Relation Between Hydrologic Factors, Size of Drainage Area, Required Amounts of Water, and Dimensions of the Pond:-

For any given period of time and range in depth for which the surface area of the pond is practically constant, the relation between the various hydrologic factors, the drainage area, and the dimensions of the pond can be expressed as follows:

$$RA - (E - P)a - U - S = da + W$$

where A (acres)	= *Size of contributing drainage area*
R (inches)	= *Runoff from the drainage area during the period under consideration*
a (acres)	= *Surface area of the pond*
E (inches)	= *Evaporation from the pond during the period under consideration*
P (inches)	= *Precipitation falling on the pond during the period under consideration*
U (acre-inches)	= *Amount of water used during the period under consideration (by livestock, in irrigation, or for other needs)*
S (acre-inches)	= *Seepage during the period*
d (inches)	= *Increase (+) or decrease (-) in depth of water during the period*
W (acre-inches)	= *Amount of water in excess of the capacity of the pond which is wasted over the spillway*

Another factor, not included in the above expression, is the loss of capacity due to silting. The nature of this factor and the limited information on sedimentation make it impracticable to include it in the quantitative relation. Silting in the Claypan Prairies can be largely eliminated by keeping the area adjoining the pond in grass. Water from springs is not considered because in the areas under consideration few, if any, springs exist on drainage areas of less than 500 acres. The flow of such springs as may be found will be greatly diminished or will disappear entirely during critical periods.

In the Claypan Prairies, where seepage and silting ordinarily can be neglected if the site is properly selected and the area adjoining the reservoir is kept in good pasture, the relation for critical periods, when the water supply does not exceed the capacity of the reservoir, may be expressed:

$$RA - (E - P)a - U = da \quad \text{------------} \quad (1)$$

Note: In cases where seepage cannot be eliminated, its amount must be estimated in acre-inches and added to the value of U.

In the application of this relation, it is necessary to determine (1) amounts of evaporation, precipitation, and of runoff that can be expected to be equaled or exceeded 75, 80, 90, and 96 percent of the time, and (2) the lengths of critical periods. This must be done on a seasonal rather than annual basis because runoff, precipitation, evaporation, and use of water are decidedly seasonal in character. The distribution of precipitation and evaporation and the relation between precipitation and runoff in the Claypan Prairies require the consideration of 2 seasons--May to September (5 months) and October to April (7 months)--and of critical periods of 5, 17, and 29 months including 1, 2, and 3 summer seasons (May to September), respectively. The variation in evaporation and precipitation in the various parts of the Claypan Prairies made it necessary to divide them into the 4 zones shown in *figure 1*, and to make separate determinations of amounts of $E - P$ and R for each. The same seasons and critical periods were found to apply to all 4 zones. Precipitation and evaporation do not change abruptly, as the boundary between zones 2 and 3 in *figure 1* would imply. In practice however, it is necessary to draw definite lines at which the values used in design should be changed.

Definition of Mean Surface Area:-

The relation $RA - (E - P)a - U = da$ applies strictly only when a is *practically constant.* However, in view of uncertainties in the determination of values of R and of $(E - P)$ for various expectancies, the work of calculating and using a number of surface areas in designing a pond seldom would be justified. If the mean surface area for the entire pond is properly determined, the error introduced by applying it to the full depth is not likely to be inconsistent with the uncertainties in the basic data used.

The mean surface area of any pond can be readily obtained from the total volume and maximum depth below spillway elevation or from the following expression:

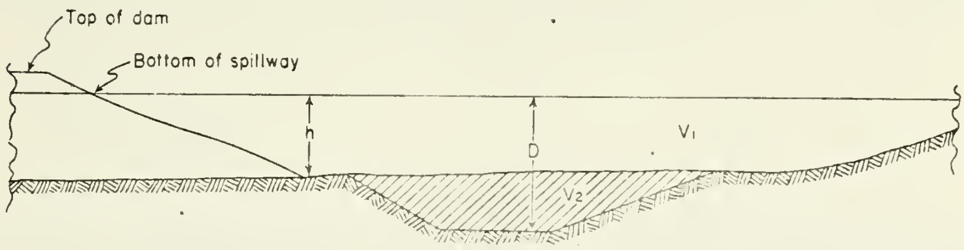
$$a \text{ (in acres)} = \frac{B + T + 4M}{6}$$

where B = Area at the bottom of the pond, in acres

T = Area at spillway elevation in acres

M = Area at mid-depth, in acres

The great majority of small farm ponds are neither entirely in excavation nor entirely natural. The actual condition existing in most cases is illustrated in *figure 2*:



V_1 = Volume above natural ground

V_2 = Volume of excavation

FIGURE 2.--Section through typical small farm ponds

(For ponds wholly in excavation, the bottom of the spillway is at or below natural ground and h and $V_1 = 0$. For natural ponds, with borrow pits off the pond sites, $V_2 = 0$ and $D = h$.)

The excavated portion V_2 is usually an appreciable portion of the total volume. When the borrow pit for the dam or dike is off the pond area, there is no excavation and the entire volume of the pond is above the natural ground and is equal to V_1.

The mean surface area for cases illustrated in *figure 2* is $\frac{V_1 + V_2}{D}$ acres where V_1 and V_2 are in acre-feet and D is in feet. The volume of excavation, V_2, usually is determined by the available funds and is known in advance.

When the pond is entirely in excavation, which would be the case when the site is level or practically so, the mean surface area in acres is $\frac{V_2}{1{,}614\,D}$, where V_2 = excavation in *cubic yards* and D = maximum depth in feet.

With the mean surface area a determined in the manner just outlined, the expression $RA - (E - P)a - U = Da$ is applied to the entire depth of the pond D for critical periods when the net supply does not exceed the capacity of the pond. It is of utmost importance to remember this in applying the information and procedures outlined in this report. If either the bottom or top areas are used instead of the mean surface area, the results will be grossly in error and the work spent in applying the information and procedures will be completely wasted.

Equations and Formulas:-

From the relation $RA - (E - P)a - U = Da$, it follows that:

(a) To provide a dependable supply in a farm pond, the total volume (Da) must equal or be greater than the difference between the total demand and the total supply during the critical period, that is, $Da \geqq U + (E - P)a - AR$. For critical periods, the minimum allowable mean surface area of a pond with a depth D is obtained by solving the above expression for a thus:

$$a \geqq \frac{U - AR}{D - (E - P)} \quad \text{------------------} \quad (2)$$

(b) To maintain a dependable supply in a pond, the total supply, during critical periods following the filling of the reservoir, plus the total volume of water in the pond, must equal or be greater than the total demand during the period that is, $AR + Da \geqq U + (E - P)a$.

From this expression, the minimum drainage area required to maintain a dependable supply is:

$$A \geqq \frac{U + (E - P - D)a}{R} \quad \text{------------------} \quad (3)$$

(c) To fill a reservoir within a reasonable time after completion or after emptying, (17 months or 29 months, beginning in May), the total supply during this period must equal or be greater than the total demand plus the total volume of the pond, or $AR \geqq U + (E - P)a + Da$. Solving this for A gives the following expression for the minimum drainage area required to fill the pond:

$$A \geqq \frac{U + (E - P + D)a}{R} \quad \text{------------------} \quad (4)$$

where $(E - P)$ and R are amounts for 17 or 29 months that can be expected to be equaled or exceeded 75 percent of the time.

Other relations which are not used directly in the hydrologic design but may be useful in pond management include:

> To prevent excessive waste over the spillway, the drainage area should not exceed that required to fill the pond within a reasonable time of completion and to provide a sufficient water supply during critical periods.
>
> For a given mean surface area of pond, greater depth wi l provide more storage, and less water will be wasted over the spillway.
>
> For a period when $RA - (E - P)$ is equal to or less than U, there will be no waste.
>
> During droughts, the same storage in a deep pond will supply water for longer periods than that in a shallower one.
>
> The increase in depth of water due to a given depth of precipitation falling on the pond is independent of the surface area or the depth of the reservoir.
>
> The increase in depth of water in the pond resulting from a given amount of runoff from the drainage area varies inversely with the surface area of the pond--the greater the area of the pond, the smaller the increase in depth produced by a given amount of runoff.
>
> The decrease in depth resulting from a given use will vary inversely with the surface area of the pond.

Design Values:-

Values of R and $(E - P)$ with expectancies of 75, 80, 90, and 96 percent of time for use in expressions (2), (3), and (4) were determined for each of the 4 zones shown in *figure 1* and are given in *table 1*. The values of R are for moderately grazed pastures or for drainage areas in mixed crops. Values of runoff from terraced and unterraced land entirely in cultivation, which would be greater, are not given because in the Claypan Prairies it is neither necessary nor advisable to use such drainage areas for farm ponds. Watersheds entirely in cultivation will seldom exceed 20 or 30 acres. If cultivated areas should be used, it still will be necessary to keep the lower portion of the watershed in grass, which in effect would change it from cultivated to mixed cover.

The values of P for 5, 17, and 29 months in *table 1* are minimum total depths which can be expected 75, 80, 90, and 96 percent of the time, while E are maximum depths for the same expectancies. The combination of minimum precipitation and maximum evaporation was used because usually evaporation is high when precipitation is low. It will be noted that evaporation exceeds precipitation in all zones for all periods, and it is for this reason that $E - P$ is higher for the higher expectancies. The values of R are based on a rainfall-runoff relation derived from the records from the several experimental watersheds. Runoff is not a straight-line function of precipitation. Neither does the same relation hold for the summer and winter seasons in the 4 zones. This accounts for the variations between periods and between zones.

TABLE 1.--*Values of E, P, E - P, and R in inches for various expectancies and critical periods in the 4 zones of the Claypan Prairies.*

Expectancy % of time	5 months				17 months				29 months			
	E	*P*	*E - P*	*R*	*E*	*P*	*E - P*	*R*	*E*	*P*	*E - P*	*R*
	in.	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
	Zone 1 (Southern Illinois and Indiana)											
75	-	-	-	-	74	53	21	6.45	117	92	25	15.5
80	32	13	19	0.27	76	52	24	5.85	119	90	29	14.0
90	34	11	23	.08	80	48	32	3.55	123	86	37	11.4
96	36	9	27	.0	83	43	40	1.30	127	80	47	7.5
	Zone 2 (Northwestern Illinois and Iowa)											
75	-	-	-	-	67	46	21	2.55	107	78	29	6.45
80	29	15	14	.55	69	45	24	2.10	110	76	34	5.40
90	30	13	17	.26	73	41	32	.78	116	70	46	3.0
96	32	10	22	.05	78	38	40	.30	122	64	58	1.5
	Zone 3 (Northeastern Missouri)											
75	-	-	-	-	77	52	25	5.9	118	88	30	12.7
80	32	16	16	.75	80	51	29	5.3	122	86	36	11.3
90	36	14	22	.40	88	47	41	3.0	132	83	49	9.3
96	42	12	30	.17	96	45	51	2.1	141	80	61	7.5
	Zone 4 (Western Missouri, Kansas, and Oklahoma)											
75	-	-	-	-	103	49	54	4.10	161	82	79	8.7
80	45	16	29	.75	105	48	57	3.55	165	80	85	7.5
90	50	14	36	.40	112	44	68	1.65	173	75	98	5.0
96	56	13	43	.26	120	39	81	.60	180	70	110	3.0

Illustrative Problems:-

Ponds intended for fish production, recreation, supplemental irrigation, and other uses requiring either large amounts of water or ponds in which only minor fluctuations in depth of water can be permitted should be designed by the application of expressions (2), (3), and (4) on *page 9*, using the values given in *table 1*. The following numerical examples illustrate the procedure to be followed in the design of such developments:

In the following problems an expectancy of 96 percent of time was used. In actual practice, either the 96, 90, or 80 percent expectancies may be selected, depending on the cost and purpose of the developments:

PROBLEM 1

Determine minimum depth of pond required to furnish a dependable supply under the following conditions:

LOCATION: Near Sparta, Illinois

REQUIRED AMOUNT OF WATER: 36 acre-inches per annum are required for a small herd of cattle and supplemental irrigation. Of the 36 acre-inches, 33 will be used during the May to September season and 3 during the October to April season.

DRAINAGE AREA: The drainage area above the best available site consists of 30 acres of moderately grazed pasture.

MAXIMUM DEPTH OF POND: Characteristics of the site and legal and economic considerations limit the depth (height of the dam from bottom of pond to bottom of spillway) to 20 feet.

BORROW PIT: The material for the fill is to be obtained from an off-site borrow pit.

POND SITE: Borings indicate a stratum of very low permeability at an average depth of about 16 inches. A contour map of the site gives the following volumes and mean surface areas for several heights of dam:

Depth D	Mean Surface Area a		Volume V_1	
feet	*inches*	*acres*	*acre-inches*	*acre-feet*
10	120	.20	24	2.0
11	132	.30	40	3.3
12	144	.39	56	4.7
13	156	.45	70	5.9
14	168	.53	83	6.9
15	180	.59	106	8.9
16	192	.67	129	10.7
18	216	.84	182	15.1
20	240	1.02	245	20.4

SOLUTION OF PROBLEM 1

Figure 1 shows the location to be in *zone 1.*

Step 1. From *table 1* obtain 96 percent values of R and $(E - P)$ for the 3 critical periods in zone 1. With the required amount of water and the distribution given above, compute values of U for 5, 17, and 29 months and arrange the values as follows:

Critical Period	R	$(E - P)$	U
months	*inches*	*inches*	*acre-inches*
5	0	27	33 (May-Sept.)
17	1.3	40	69
29	7.5	47	105

Step 2. Determine minimum mean surface area and corresponding depth D of pond. To maintain a dependable supply, the mean surface area a must equal or be greater than $\frac{U - AR}{D - (E - P)}$, or than $\frac{U}{D - (E - P)}$ when $R = 0$ (see p. 9).

For a 10-foot depth:-

$D = 120$ inches and $a = 0.20$ acre which is smaller than $\frac{33}{120 - 27}$. A pond with $D = 10$ feet and $a = 0.20$ acre will therefore fail during a 5-month critical period.

For an 11-foot depth:-

$D = 132$ inches and $a = 0.3$ acre which is smaller than $\frac{33}{132 - 27}$.

For a 12-foot depth:-

$D = 144$ inches and $a = 0.39$ acre which is greater than $\frac{33}{144 - 27}$. We can therefore not consider a reservoir less than 12 feet deep.

Note: In practice it may be advisable to consider intervals less than 1 foot.

Step 3. Determine whether a drainage area of 30 acres will be sufficient to maintain a dependable supply during critical periods of 17 and 29 months in a pond 12 feet deep and a mean surface area of 0.39 acre.

To maintain a dependable supply the drainage area A must equal or be greater than

$$\frac{U + (E - P - D)a}{R} \quad \text{(see p. 9)}$$

To maintain the supply over a 17-month critical period in a pond with $D = 144$ (12 ft.) and $a = 0.39$ acre, the minimum drainage area required is

$$A = \frac{69 + (40 - 144)\ 0.39}{1.3} = 22 \text{ acres}$$

For a critical period of 29 months

$$A = \frac{105 + (47 - 144)\ 0.39}{7.5} = 9.0 \text{ acres}$$

A pond 12 feet deep will therefore be adequate to maintain a dependable supply after the pond is once filled.

Step 4. Determine minimum drainage area required to fill a pond with $D = 12$ feet and $a = 0.39$ acre.

To fill a pond within a reasonable time after completion, the drainage area A must equal or be greater than

$$\frac{U + (E - P + D)a}{R} \quad \text{(see p. 9)}$$

where $(E - P)$ and R are the 17 months 75 percent values in table 1.

For zone 1: $E - P = 21$ inches, $R = 6.5$ inches.
Required amount of water U for 17 months = 69 acre-inches.
Minimum drainage area required to fill the pond is therefore

$$A = \frac{69 + (21 + 144)\ 0.39}{6.5} = 20.5 \text{ acres}$$

The 30-acre drainage area will therefore be adequate to fill the pond within a 17-month period from the time of completion.

> *Note: A greater depth D would have to be tried if either of the computations in step 3 gave values of A greater than 30 acres. If the value obtained in step 4 were greater than 30 acres, a longer period might be allowed for filling, in which case the 29 months 75 percent values given in table 1 would be used.*

CONCLUSIONS: *The minimum depth (bottom of pond to spillway level) required to provide a dependable supply of 36 acre-inches per annum is 12 feet, provided seepage in the pond and through the dam is practically eliminated and excessive silting is prevented. If a grassed spillway is to be used or if wastage over the spillway must be kept to a minimum for any other reason, the drainage area should, if possible, be reduced to 22 acres by diversion.*

PROBLEM 2

Determine maximum dependable supply under the following conditions:

LOCATION: Roger County, Oklahoma

REQUIRED WATER SUPPLY: The possibility of supplemental irrigation of feed crops is being considered. Except for 6 acre-inches to be used by a small herd of cattle (3 ac.-in. during May to September and 3 during October to April), the entire available supply will be used for irrigation during the growing season (May to September).

DRAINAGE AREA: The drainage area above the best pond site is 100 acres of land in mixed crops.

HEIGHT OF DAM: Available funds and physical characteristics of the site fix the elevation of the bottom of the spillway at 20 feet above the bottom of the natural ground (h of *fig. 2* = 20 ft.).

VOLUME OF POND: Material for the fill will be taken from the pond site. Volume of excavation V_2 required for the fill is 2.5 acre-feet (about 4,000 cu. yds.). From a survey of the site, volume V_1 for h = 20 feet is found to be 36.2 acre-feet. Total volume $V_1 + V_2$ = 38.7 acre-feet or 465 acre-inches.

TOTAL DEPTH OF COMPLETED POND: The maximum depth of excavation is to be 5 feet below natural ground at the dam. Total depth D is therefore $h + 5 = 20 + 5 = 25$ feet.

MEAN SURFACE AREA: With a total volume of 38.7 acre-feet and a total depth of 25 feet, the mean surface area $a = \frac{38.7}{25} = 1.55$ acres.

SOLUTION OF PROBLEM 2

Figure 1 shows the location to be in *zone 4*.

Step 1. Determine maximum allowable use of water to permit filling of the pond. From the expression $AR \geq U + (E - P)a + Da$ *(see par. (c), p. 9)*, we find that the use U must not exceed $AR - (E - P)a - Da$, where R and $E - P$ are the 75 percent values for 17 or 29 months given in *table 1*.

For zone 4:

R = 4.1 inches and $E - P$ = 54 inches for 17 months
R = 8.7 inches and $E - P$ = 79 inches for 29 months

With these values and the given A, D, and a, we get for 17 months

$$(100 \times 4.1) - (54 \times 1.55) - 465 = -139 \text{ acre-inches}$$

which means that at the end of 17 months the pond may lack 139 acre-inches of being full even if no water is used during the period. In view of the purpose of the pond it may be feasible to allow 29 months for filling, in which case U during the 29 months may not exceed

$$(100 \times 8.7) - (79 \times 1.55) - 465 = 283 \text{ acre-inches}$$

Step 2. Determine maximum dependable supply that can be maintained after the pond is filled. From the expression $AR + Da \gtreqless U + (E - P)a$ (see par. (b), p. 9), we find that, to maintain a dependable supply during periods following the filling of the pond, U should not exceed $AR + Da - (E - P)a$, where $E - P$ and R are the 96 percent values for zone 4 given in *table 1* for the 3 critical periods. These values are:

Critical Period	$E - P$	R
months	*inches*	*inches*
5	43	0.26
17	81	.60
29	110	3.00

With the above data and the given values of A, D, and a, we find the following allowable values of U:

For 5 months, $(100 \times 0.26) + 465 - (43 \times 1.55) = 424$ acre-inches

For 17 months, $(100 \times 0.6) + 465 - (81 \times 1.55) = 399$ acre-inches

For 29 months, $(100 \times 3.0) + 465 - (110 \times 1.55) = 595$ acre-inches

Neglecting the value for 5 months which, per growing season, is much higher than those for 17- and 29-month periods, and deducting amounts required for cattle (9 ac.-in. for 17 months and 15 for 29 months), we find

$$\frac{399 - 9}{2} = 195 \text{ acre-inches per growing season}$$

$$\frac{595 - 15}{3} = 193 \text{ acre-inches per growing season}$$

which means that, having once filled, the pond will provide a dependable supply of 193 acre-inches per growing season. Calculations for periods longer than 29 months would show greater amounts available for use.

CONCLUSIONS: *No water for supplementary irrigation should be expected during the first and second seasons after completion. About 193 acre-inches (16 ac.-ft.) per growing season may be expected to be available for irrigation after the pond is once filled.*

Dimensions of Excavated Ponds:-

When excavation is involved and particularly when the pond is wholly or nearly wholly in excavation, it is also necessary to determine the dimensions of the pond which for a given total depth will result in various total volumes and therefore various mean surface areas. For excavated ponds with uniform side slopes and with top surface areas nearly horizontal and approximating regular geometric shapes, the dimensions of the surface area of the pond at the original ground surface can be readily computed. The horizontal sections of most excavated ponds are either roughly circular or rectangular. Formulas for computing the top diameters of circular ponds and the top widths of rectangular ponds are given below:

For circular ponds:-

$$\text{Top diameter} = SD + \sqrt{34.36\frac{V}{D} - \frac{(SD)^2}{3}}.$$

where S *is the side slope (ratio of horizontal to vertical dimension)*

D *is the depth in feet*

V *is the volume in cubic yards*

For $S = 3$, $D = 8$ feet, and $V = 1,200$ cubic yards,

$$\text{The top diameter} = 24 + \sqrt{34.4\frac{1,200}{8} - \frac{(24)^2}{3}} = 94.5 \text{ feet}$$

For rectangular ponds:-

$$\text{Top width} = \frac{(PSD + SD) + \sqrt{(PSD + SD)^2 - 4P\left[\frac{4}{3}(SD)^2 - \frac{27\,V}{D}\right]}}{2P}$$

where P *is the ratio of top length to top width*

S *is the side slope (ratio of horizontal to vertical dimension)*

D *is the depth in feet*

V *is the volume in cubic yards*

For $S = 3$ and $P = 1.5$, this formula reduces to

$$\text{Top width} = 2.5\,D + \sqrt{18\frac{V}{D} - 1.75\,D^2}$$

Values of top diameters for circular excavations and top widths for rectangular excavations with length 1.5 times the width are given in *table 2* for 3:1 side slopes.

Table 2.—*Top dimensions in feet of excavated circular and rectangular ponds with 3:1 side slopes for various volumes and depths.*

Volume of Excavation	Depths 3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.
cu. yards	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*	*feet*
			Top Diameters of Circular Ponds					
200	56.5	52.9	51.1	50.2	*	*	*	*
300	67.0	61.5	58.8	57.3	56.8	56.5	*	*
400	76.4	70.2	66.7	64.7	63.7	63.1	*	*
500	84.3	76.8	72.5	70.0	69.0	68.0	67.6	67.2
600	91.7	83.4	78.6	75.7	73.9	72.8	72.3	71.9
700	98.3	89.0	83.8	80.2	78.0	76.9	76.2	75.6
800	104.5	94.6	88.6	84.9	82.5	81.0	80.0	79.2
900	110.0	99.6	93.3	89.0	86.2	84.7	83.6	82.8
1,000	115.6	104.2	97.7	93.0	90.0	88.0	86.8	86.0
1,100	121.0	108.9	101.7	96.7	93.2	91.2	90.0	89.0
1,200	126.0	113.5	105.4	100.3	96.8	94.5	92.9	91.9
1,300	130.6	117.2	109.2	103.5	99.8	97.5	95.9	94.6
1,400	135.0	121.1	112.8	107.0	103.0	100.3	98.5	97.2
1,500	139.7	125.0	116.1	110.0	105.8	103.0	101.0	99.8
1,600	144.3	129.0	119.4	113.2	108.8	105.8	103.6	102.1
1,700	148.0	132.1	122.9	116.0	111.2	108.4	106.0	104.3
1,800	152.1	135.7	126.0	119.0	114.2	110.9	108.2	106.8
1,900	156.2	139.0	129.0	121.8	116.7	113.2	110.4	108.7
2,000	160.3	142.8	132.0	124.5	119.0	115.7	112.8	110.9
2,100	164.0	146.0	135.0	127.0	121.8	118.0	114.9	112.9
2,200	167.7	149.2	137.9	129.7	124.1	120.0	117.0	115.0
2,300	171.0	152.5	140.5	132.0	126.6	122.3	118.9	117.0
2,400	174.8	155.5	143.1	134.6	128.9	124.6	121.0	118.9
2,500	178.0	158.6	145.7	137.0	131.1	126.5	122.9	120.8
2,600	181.3	161.3	148.4	139.0	133.2	128.4	125.0	122.8
2,700	184.4	164.1	150.8	141.5	135.4	130.7	127.0	124.6
2,800	187.9	166.9	153.6	144.0	137.6	132.8	129.0	126.6
2,900	190.9	169.3	155.7	146.0	139.6	134.8	130.9	128.2
3,000	194.2	172.3	158.2	148.7	141.8	136.7	132.9	130.0
			Top Widths of Rectangular Ponds with Lengths = 1.5 the widths					
200	41.8	39.5	38.5	*	*	*	*	*
300	49.6	46.3	44.4	43.5	*	*	*	*
400	56.3	52.2	49.9	48.8	48.2	*	*	*
500	62.3	57.1	54.1	52.7	51.9	*	*	*
600	67.3	61.7	58.5	56.7	55.7	55.2	*	*
700	72.5	66.0	62.3	60.4	58.8	58.2	*	*
800	76.6	69.7	65.8	63.3	61.9	61.1	*	*
900	81.0	73.6	69.0	66.5	64.5	63.6	63.2	*
1,000	84.9	77.0	72.1	69.2	67.4	66.2	65.6	*
1,100	88.5	80.1	75.0	72.0	69.9	68.8	68.0	67.5
1,200	92.2	83.3	77.9	74.6	72.2	71.0	70.0	69.5
1,300	95.5	86.1	80.5	77.0	74.5	73.1	72.1	71.5
1,400	98.8	89.0	83.0	79.5	76.8	75.2	74.0	73.3
1,500	102.0	91.7	85.4	81.6	78.9	77.1	76.0	75.2
1,600	105.4	94.7	88.1	84.0	81.0	79.1	77.8	77.0
1,700	108.2	96.9	90.1	86.0	82.8	81.0	79.6	78.7
1,800	111.0	99.4	92.4	88.0	84.8	82.8	81.2	80.2
1,900	113.9	101.8	94.6	90.0	86.6	84.5	82.9	82.0
2,000	117.0	104.7	97.1	92.1	88.6	86.2	84.6	83.5
2,100	119.4	106.5	98.8	94.0	90.2	87.9	86.0	85.0
2,200	122.0	108.8	100.9	95.8	92.0	89.5	87.6	86.4
2,300	124.7	111.0	102.9	97.5	93.8	91.0	89.1	88.0
2,400	127.5	113.9	105.2	99.4	95.5	92.6	90.7	89.4
2,500	130.0	115.4	106.8	101.2	97.1	94.2	92.2	90.8
2,600	132.4	116.2	109.0	102.8	98.7	95.8	93.7	92.2
2,700	134.8	119.8	110.5	104.5	100.3	97.2	95.0	93.6
2,800	137.1	122.2	112.5	106.2	101.8	98.7	96.4	94.9
2,900	139.4	124.3	114.8	107.8	103.2	100.0	97.8	96.1
3,000	141.7	126.2	116.4	109.5	104.5	101.5	99.0	97.3

* impossible or impractical to excavate with 3:1 or flatter side slopes

Simplified Procedure for Small Ponds:

In small ponds intended primarily for stock water, fairly wide fluctuations in the depth of water may be permitted without greatly impairing the value of the pond as a source of water for livestock. The cost of such small ponds including appurtenances such as watering troughs and fences which seldom exceeds $500 may not justify even the simple surveys and computations involved in using the expressions (2), (3), and (4) presented in the foregoing paragraphs. It was therefore necessary to make a number of assumptions which would permit the development of a direct and simple method which could be used in planning such ponds in the fields.

By limiting the total capacity of such ponds to 3 acre-feet, confining the total cost to $500, and by making further permissible assumptions, it was possible to develop a simplified procedure for the design of small ponds which can be expected to provide a dependable supply of water up to 12 acre-inches per annum.

In developing the simplified procedure, it was assumed that for unexcavated ponds on small drainage areas the ratio of mean surface area to the surface area at spillway elevation for a given depth can for practical purposes be considered constant. The values of this ratio and the relation between surface areas at various depths were derived by Mr. W. D. Potter from detailed topographic maps of a large number of experimental watersheds in various parts of the United States and from data on farm ponds constructed by the Soil Conservation Service. The values derived by Mr. Potter were verified by the authors for a large number of ponds in the Claypan Prairies.

Separates based on this publication were prepared and made available for use in design of small farm ponds in the Claypan Prairies of Illinois and Indiana, Iowa, Missouri, Kansas, and Oklahoma. These separates include also values of rates of runoff based on Part II of this publication for use in the design of spillways on small ponds and of other conservation structures.

REFERENCES ON CONSTRUCTION AND MANAGEMENT OF FARM PONDS

The hydrologic design outlined in the preceding pages is basic and most important in insuring a dependable water supply in a farm pond. It is, however, not the only factor to be considered. Suitable spillways must be provided to safely dispose of excess water. Sound construction procedures must be followed in building dams and in excavation. Suitable appurtenances such as watering trougns, pipes, and valves must be properly installed. The dams and dikes must be properly protected. In addition to the construction phases, there are the management problems such as proper stocking of fish ponds, control of weeds and of aquatic vegetation, fertilizing to provide food for fish, controlling the number and size of fish, and various other biological problems involved in the management of farm ponds for fish, wildlife, livestock, and domestic use. The sanitation aspect, including malaria hazard, must always be kept in mind. These problems and many others not mentioned are beyond the scope of this publication. It will, however, be well to call attention to a number of publications issued by the Soil Conservation Service and other agencies which contain information on the hydraulic characteristics of grassed waterways and of structures used as spillways on farm ponds, on methods of construction and protection of farm ponds, and on the management of ponds for fish and wildlife. These publications include:

More Farm Ponds Needed, by Howard Matson (a Preliminary Report of the Subcommittee on Ponds and Reservoirs of the American Society of Agricultural Engineers, Agricultural Engineering, Vol. 21, No. 11, November 1943

A Report on Farm Reservoirs, by A. W. Zingg (to be published as a bulletin of the Missouri Agricultural Experiment Station)

Stock-Water Developments - Wells, Springs, and Ponds, by C. L. Hamilton and Hans G. Jepson, Farmers' Bulletin No. 1859, USDA

Fundamental Hydrologic Considerations for the Design of Impounding Reservoirs in the Middle West, by E. L. Waterman, F. T. Mavis, and Edward Soucek, reprint from Journal of the American Water Works Assoc., Vol. 28, No. 2, February 1936

Specimen Plans and Information to be Used in the Design of Small Earth Dams in Oklahoma, by W. C. Burnham, Oklahoma Planning and Resources Board, Div. of Water Resources, 1938

Construction and Management of Farm Ponds, by John R. Carreker, Agricultural Engineering, February 1945

Low Dams, National Resources Committee, 1938

Fish for Food from Farm Ponds, by Verne E. Davison and J. A. Johnson, Farmers' Bulletin No. 1938, USDA

Ponds for Wildlife, by Philip F. Allan and Cecil N. Davis, Farmers' Bulletin No. 1879, USDA

Techniques of Fish Pond Management, Miscellaneous Publication No. 528, USDA

Farm Fish Ponds, by C. E. Addy, C. F. DeLaBarree, and D. W. Cardwell, June 1942, Va. Polytechnic Institute

Management of Farm Fish Ponds, by H. S. Swingle and E. V. Smith, Bulletin 254, April 1942, Ala. Polytechnic Institute

Tests on Vegetated Waterways, by Maurice B. Cox, Technical Bulletin No. T-15, Oklahoma Agricultural and Mechanical College

Larger Aquatic Plants of Oklahoma with Special Reference to Their Value as Fish Culture, Technical Bulletin, Oklahoma Agricultural Experiment Station, 1938, by James de Gruchy

Water Willows for Shoreline Erosion Control in Farm Ponds, by Horace J. Harper, Soil Conservation, March 1944

Grassed Waterways for Handling Runoff from Agricultural Areas, by C. E. Ramser, Agricultural Engineering, Vol. 24, No. 12, pp. 412-18, December 1943

Tests of Bermuda Grass Channel Linings, by R. L. Burt under the supervision of W. O. Ree, Release No. 3, SCS mimeographed publication, September 1939

Tests of a Centipede Grass Channel Lining, by W. O. Ree, Release No. 4, SCS mimeographed publication, August 1940

Hydraulic Tests of Kudzu as a Conservation Channel Lining, by W. O. Ree, Agricultural Engineering, January 1941, pp. 27-29

Characteristics of Some Meadow Strip Vegetations, by H. L. Cook and F. B. Campbell, Agricultural Engineering, September 1939, pp. 345-48

Laboratory Tests of Bluegrass Terrace Outlet Channels, by D. D. Smith, Agricultural Engineering, October 1943, pp. 333-6, 342

Report on Tests Made on Three Types of Flume Entrance, by Fred W. Blaisdell and Albert N. Huff, St. Antnony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, Minnesota, SCS multilithed publication, August 1944

The SAF Stilling Basin, by F. W. Blaisdell, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, SCS multilithed publication, December 1943

Hydraulic Design of Rectangular Spillways, by A. N. Huff, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, SCS mimeographed publication, October 1943

Erosion Control Structures - Drop Inlets and Spillways, by Lewis Hanford, Kessler Research Bulletin 122, USDA, etc., Agricultural Experiment Station and Engineering Experiment Station, Wisconsin, June 1934

Hydraulic Design of Drop Structures for Gully Control, by B. T. Morris and D. C. Johnson (Cal. Tech.), Paper No. 2198, Reprinted from Transactions of American Society of Civil Engineers, Vol. 108, pp. 887-940 (1943)

Baffle Type of Energy Dissipator for Pipe Outlets, by V. A. Vanoni, J. T. Rostrom, Agricultural Engineering, August and September 1944, pp. 301 and 341

Tests of a Standard Culvert Outlet for Use with Drop Inlet Culverts, by Fred W. Blaisdell, SCS mimeographed publication, October 1941

Flow of Water in Vegetal Lined Waterways, by W. O. Ree and V. J. Palmer, in manuscript

Preliminary Results of Tests on Pipe Bleeders Laid on Steep Slopes, by F. W. Blaisdell, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis, SCS mimeographed publication, November 1942

The Capacities of Rectangular Notches, by W. O. Ree, Release No. 2, SCS mimeographed publication, December 1938

Flow of Water in Flumes, by F. C. Scobey, Technical Bulletin No. 393, 1933, USDA

Flow of Water in Irrigation and Similar Canals, by Fred C. Scobey, T. B. No. 652, USDA, 1939

The Flow of Water in Riveted Steel and Analogous Pipes, by Fred C. Scobey, T. B. No. 150, USDA, 1930

Flow of Water in Concrete Pipe, by Fred C. Scobey, (USDA bull. (Prof. Paper) No. 852 reprinted 1924)

PART II. RATES OF RUNOFF FOR USE IN DESIGN OF SPILLWAYS AND OTHER CONSERVATION STRUCTURES

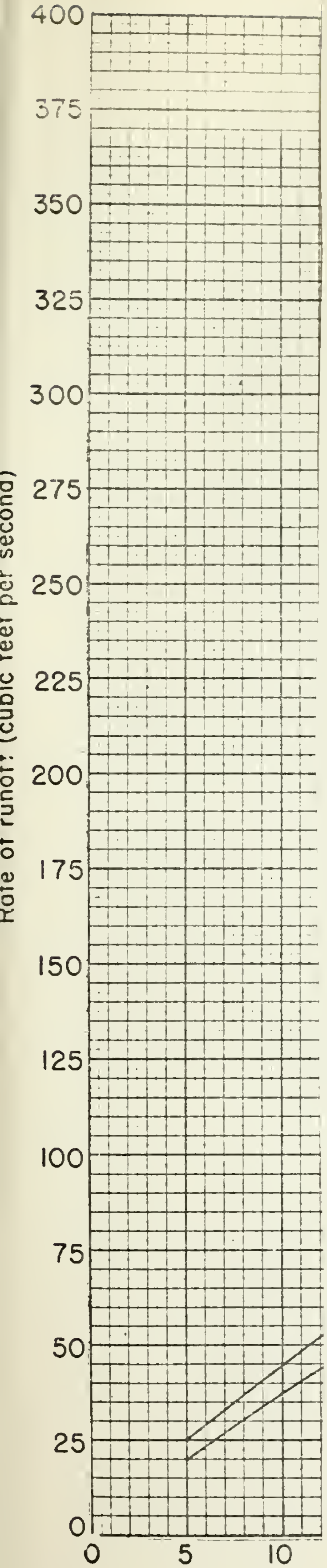
Rates of runoff are determined by the following factors: Size of drainage area; intensities and amounts of rainfall; moisture content of the soil; texture, structure, and depth of soil; vegetal cover and tillage; physiographic features such as configuration, shape, and degree of dissection (drainage density); and slopes and other hydraulic characteristics of channels and watercourses. The records of maximum rates of runoff from the several experimental watersheds in the Claypan Prairies were analyzed with the above factors in mind. The results of this analysis are given in *figures 3 and 4*. A good portion of the land included in the area of application *(fig. 1)* is devoted to permanent pasture. This makes it necessary to consider rates for grassed as well as cultivated areas even when expectancies of 25 years or longer are involved.

The Claypan Prairies lie in a region where rainfall intensities increase from the northeast to southwest. To provide for the corresponding variations in rates of runoff, the values derived from the available records were all reduced to a common base. Factors were developed by which rates obtained from *figures 3 and 4* must be multiplied when applying them in various parts of the areas of application. These factors varying from 0.95 in Indiana to 1.00 in western Illinois and 1.13 on the western edge of the areas of application are shown in *figure 1*.

The limited range in size of the experimental drainage areas in the Claypan Prairies does not permit the direct determination of variation in rates of runoff with size of drainage area. The values for the curve in *figure 4* were obtained by applying to the available records factors derived from runoff and watershed studies conducted by the Soil Conservation Service in other areas. These factors were applied only within limits deemed proper by the authors. Records from experimental areas of various sizes must be obtained in the Claypan Prairies before values for a wider range in size can be determined.

Economic considerations entering into the design of the majority of conservation structures seldom justify greater expenditures than are necessary to provide capacities required to safely dispose of flows which may be expected on the average not more than once in 25 years. On the other hand, the reduction in initial cost of small structures which may result from the use of values for shorter recurrence intervals will in most instances be small. Such reductions in cost will be represented by small savings in materials only. The curves in *figures 3 and 4* are therefore for a 25-year recurrence interval. For a 50-year interval, the values would be about 10 percent greater than those given in *figure 4*.

The values for terraced areas used in preparing *figure 3* are based on records from 2 experimental areas shown in *figures 5 and 6*. It must be pointed out that the lengths of terraces, horizontal interval between them, the grades of terraced channels, and the hydraulic properties of the terrace-outlet channels (grade, hydraulic radius, roughness, and other characteristics) all have an effect on rates of runoff from a terraced area. It is therefore more logical to base rates of runoff for terraced areas on records from individual terraces of various lengths. No such records are available for the Claypan Prairies. In view of the above, *figure 3* when used for terraced areas is intended only as a guide. The characteristics of the experimental areas shown in *figures 5 and 6* should be kept in mind. The rates given in *figure 3* may be adjusted upward or downward depending on whether the average length of the terraces in any particular case is shorter or longer than in the experimental areas. Adjustment may also be made if other characteristics of the terraces and of the terrace-outlet channels differ widely from those shown in *figures 5 and 6*.


Rate of runoff (cubic feet per second)
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
0
5
10

F

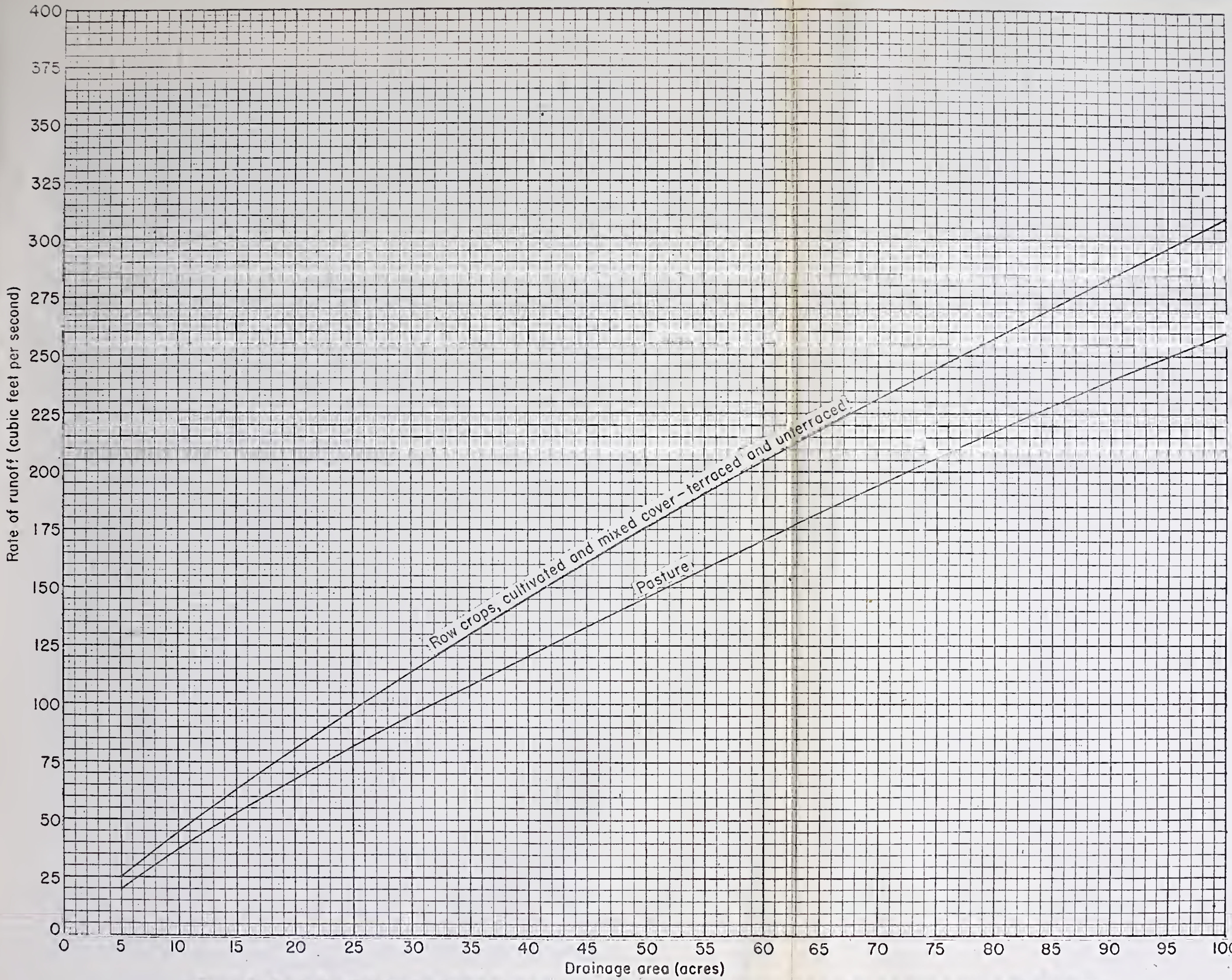


Figure 3—Rates of runoff for the design of conservation structures in the Claypan Prairies on drainage areas up to 100 acres

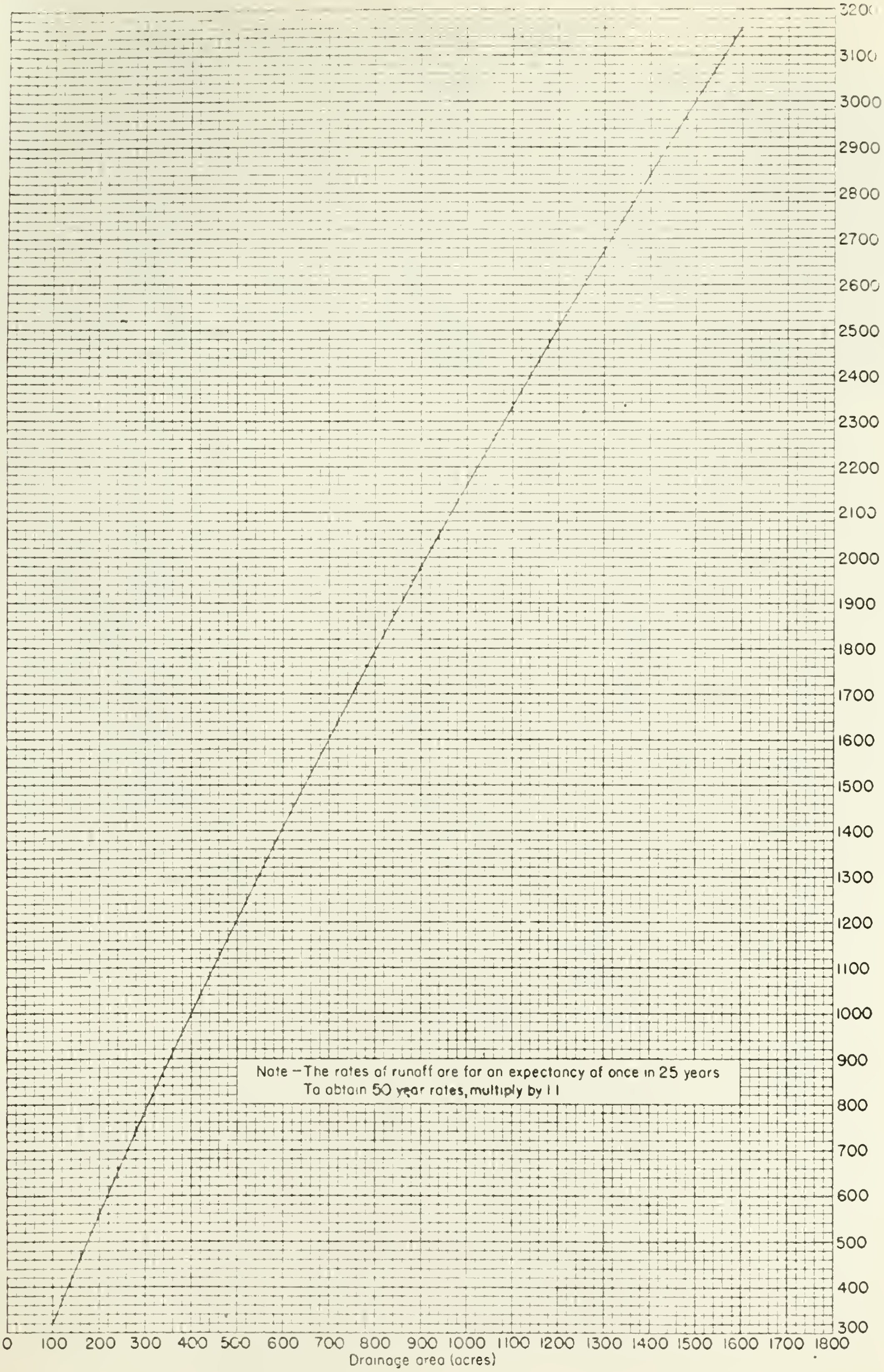
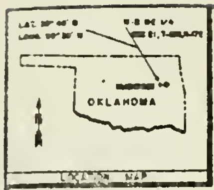


Figure 4 – Rates of runoff for the design of conservation structures in the Claypan Prairies on drainage areas in Mixed Cover ranging in size from 100 to 1600 acres

Reduction of Rates of Runoff by Spillway Storage:-

The estimated 25-year rates of runoff *(figs. 3 and 4)* are based on records of maximum rates of runoff recorded on small watersheds. The duration of these maximum rates is seldom greater than 3 or 4 minutes. Spillways on reservoirs need not be designed for such momentary rates, especially when the ratio of surface area at spillway elevation to drainage area is relatively large. No experimental studies have yet been made to determine quantitatively the permissible reductions in rates of runoff, but investigations of effect of pondage made by the authors in other studies indicate that for drainage areas of less than 50 acres with surface reservoir areas at spillway elevation greater than 0.5 acre the reduction may be as much as 30 percent or greater. For drainage areas of less than 20 acres, the values in *figure 3* may well be used without reduction; the quantities of flow are small and the structures usually are grassed waterways or small masonry structures in which reduction of capacity does not greatly affect the cost. No factor of safety need be applied to those values. For ponds and reservoirs involving larger drainage areas, recommendations for reductions must await further study and analysis.



WATERSHED CHARACTERISTICS

1. SIZE 65.4 ACRES 0.102 SQ MI
2. RANGE IN ELEVATION (APPROX M.S.L.) FROM 555
3. PREVAILING LAND SLOPE 2.7 %
4. RANGE IN LAND SLOPES FROM 1.1 % TO 3.6 %
5. LENGTH OF PRINCIPAL WATERWAY ______ FT
6. AVERAGE SLOPE OF PRINCIPAL WATERWAY ______ %
7. TOTAL NUMBER OF WATERWAYS ______
8. NUMBER OF ACRES PER WATERWAY ______
9. TOTAL LENGTH OF WATERWAYS ______
10. DRAINAGE DENSITY (LENGTH OF WATERWAYS PER A
11. FORM FACTOR A/L^2 ______

DATA ON TERRACES

TERRACE NO.	TOTAL LENGTH	TOTAL
1 NORTH	800 FEET	1.
2 N	1200	4
3 N	2350	6
4 N	2350	5
5 N	2241	5
6 N	1880	5
7 N	600	2
1 SOUTH	150	0
2 S	900	6
3 S	800	6.4
4 S	1690	5
5 S	2080	9.2
6 S	1525	5
7 S	1170	3

SOIL CHAR

SYMBOL	TYPE	ACRES	% AREA	
1	DENNIS SILT LOAM	47.35	75.88	THE DENNIS SERI GROUP THE HEAVIER RIZED. THIS SERIES POSSIBLY A MIXTURE ER THESE SOILS AR THEM IN HAVING A SURFACE SOIL IS A DEPTHS RANGING BE AND GRAY SILTY CLA MORE PERVIOUS THA
2	PARSONS SILT LOAM	16.90	23.34	THE PARSONS SILT THREE SOILS MAPPE OPED UNDER BLUEST A CHARACTERISTIC O ATIVELY IMPERVIOUS LOW THE SURFACE I COMPACT SUBSOIL RANGING FROM 18 TO UPE PENETRATION STRUCTION WILL APPRO THE SURFACE SOIL THE SUBSOIL IS LIGH
3	COLLINSVILLE STONY V.F.S.L.	1.46	2.25	THE COLLINSVILLE SOIL DEVELOPED FRO A DEPTH RANGING STONE ROCK VARYING SQUARE ARE FOUND INCHES IS A BROWN OVER THE SURFACE

SOIL C

BROWNISH GRAY SILT LOAM, SLIGHTLY LAMINATED

BROWNISH GRAY SILT LOAM THAT IS NOT LAMINATED, THE COLOR IS SLIGHTLY LIGHTER THAN THE ABOVE LAYER

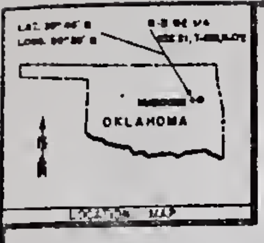
LIGHT GRAY SILT LOAM THIS LIGHT GRAY IS APPARENTLY CAUSED BY THE ACCUMULATION OF WATER ON THE LAYER BELOW

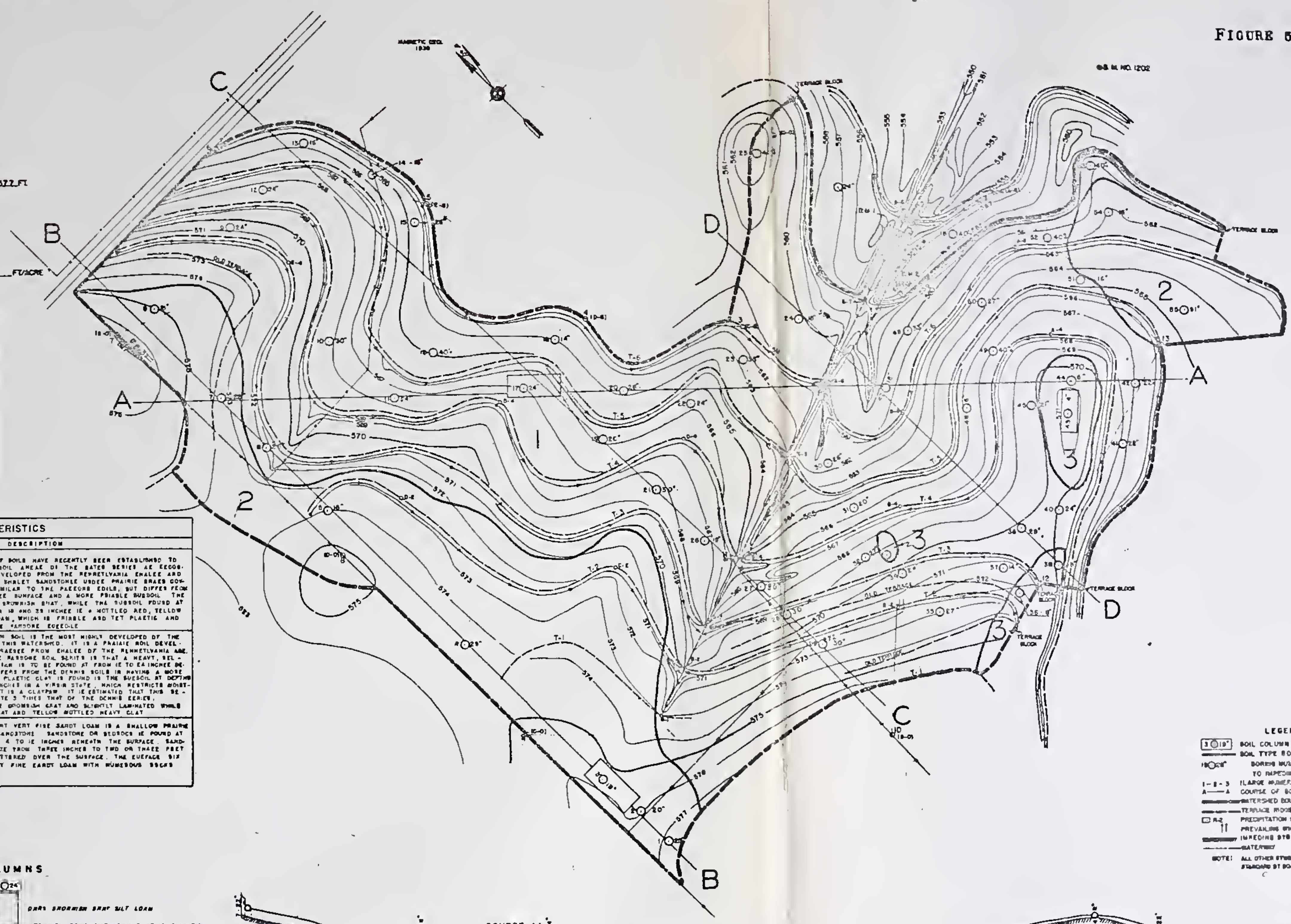
GRAY AND YELLOW MOTTLED CLAY THIS IS QUITE TOUGH AND PLASTIC

BROWN VERY FINE
STONE ROCKS SCA

SANDSTONE BEDRO

FIGURE 5





WATERSHED CHARACTERISTICS

1. SIZE 65.4 ACRES 0.102 SQ. MI.
2. RANGE IN ELEVATION (APPROX. M.S.L.) FROM 556 FT. TO 577 FT.
3. PREVAILING LAND SLOPE 2.7 %
4. RANGE IN LAND SLOPES FROM 1.1 % TO 3.6 %
5. LENGTH OF PRINCIPAL WATERWAY ______ FT.
6. AVERAGE SLOPE OF PRINCIPAL WATERWAY ______ %
7. TOTAL NUMBER OF WATERWAYS ______
8. NUMBER OF ACRES PER WATERWAY ______
9. TOTAL LENGTH OF WATERWAYS ______
10. DRAINAGE DENSITY (LENGTH OF WATERWAYS PER ACRE) ____ FT/ACRE
11. FORM FACTOR A/L^2 ______

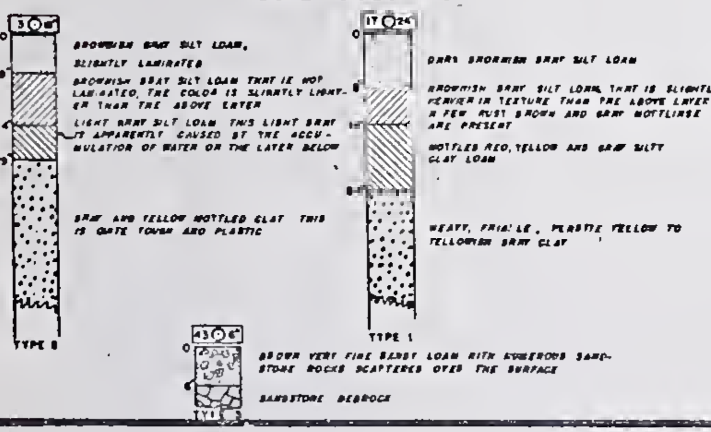
DATA ON TERRACES

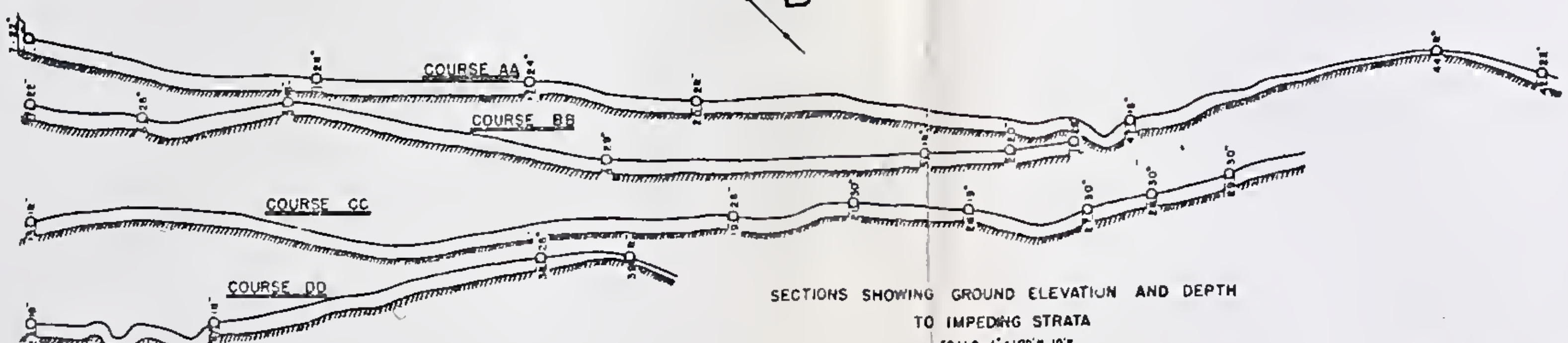
TERRACE NO.	TOTAL LENGTH	TOTAL FALL
1 NORTH	900 FEET	1.88 FT.
2 N	1200	4.90
3 N	2990	8.21
4 N	2350	8.09
5 N	2241	8.29
6 N	1990	8.98
7 N	800	2.07
1 SOUTH	150	0.87
2 S	900	4.19
3 S	900	8.48
4 S	1890	8.18
5 S	2080	8.28
6 S	1565	3.80
7 S	1170	3.98

SOIL CHARACTERISTICS

SYMBOL	TYPE	ACRES	% AREA	DESCRIPTION
1	DENNIS SILT LOAM	47.39	72.4	THE DENNIS SERIES OF SOILS HAVE RECENTLY BEEN ESTABLISHED TO GROUP THE HEAVIER SUBSOIL AREAS OF THE BATES SERIES AS RECOGNIZED. THIS SERIES IS DEVELOPED FROM THE PENNSYLVANIA SHALES AND POSSIBLY A MIXTURE OF SHALEY SANDSTONES UNDER PRAIRIE GRASS COVER. THESE SOILS ARE SIMILAR TO THE PARSONS SOILS, BUT DIFFER FROM THEM IN HAVING A DARKER SURFACE AND A MORE FRIABLE SUBSOIL. THE SURFACE SOIL IS A DARK BROWNISH GRAY, WHILE THE SUBSOIL FOUND AT DEPTHS RANGING BETWEEN 18 AND 28 INCHES IS A MOTTLED RED, YELLOW AND GRAY SILTY CLAY LOAM, WHICH IS FRIABLE AND YET PLASTIC AND MORE PERVIOUS THAN THE PARSONS SUBSOILS
2	PARSONS SILT LOAM	16.90	25.84	THE PARSONS SILT LOAM SOIL IS THE MOST HIGHLY DEVELOPED OF THE THREE SOILS MAPPED ON THIS WATERSHED. IT IS A PRAIRIE SOIL DEVELOPED UNDER BLUESTEM GRASSES FROM SHALES OF THE PENNSYLVANIA AGE. A CHARACTERISTIC OF THE PARSONS SOIL SERIES IS THAT A HEAVY, RELATIVELY IMPERVIOUS CLAYPAN IS TO BE FOUND AT FROM 12 TO 24 INCHES BELOW THE SURFACE. IT DIFFERS FROM THE DENNIS SOILS IN HAVING A MORE COMPACT SUBSOIL. HEAVY PLASTIC CLAY IS FOUND IN THE SUBSOIL AT DEPTHS RANGING FROM 18 TO 48 INCHES IN A VIRGIN STATE, WHICH RESTRICTS MOISTURE PENETRATION, AND IT IS A CLAYPAN. IT IS ESTIMATED THAT THIS RESTRICTION WILL APPROXIMATE 3 TIMES THAT OF THE DENNIS SERIES. THE SURFACE SOILS ARE BROWNISH GRAY AND SLIGHTLY LAMINATED WHILE THE SUBSOIL IS LIGHT GRAY AND YELLOW MOTTLED HEAVY CLAY
3	COLLINSVILLE STONY V.F.S.L.	1.46	2.23	THE COLLINSVILLE STONY VERY FINE SANDY LOAM IS A SHALLOW PRAIRIE SOIL DEVELOPED FROM SANDSTONE. SANDSTONE OR BEDROCK IS FOUND AT A DEPTH RANGING FROM 4 TO 12 INCHES BENEATH THE SURFACE. SANDSTONE ROCK VARYING IN SIZE FROM THREE INCHES TO TWO OR THREE FEET SQUARE ARE FOUND SCATTERED OVER THE SURFACE. THE SURFACE SIX INCHES IS A BROWN VERY FINE SANDY LOAM WITH NUMEROUS ROCKS OVER THE SURFACE

SOIL COLUMNS





SECTIONS SHOWING GROUND ELEVATION AND DEPTH TO IMPEDING STRATA

SCALE 1" = 100' H, 10' V

LEGEND

- SOIL COLUMN LOCATION
- SOIL TYPE BOUNDARY
- BORING NUMBER 19. 26" = DEPTH TO IMPEDING STRATUM
- 1 - 2 - 3 (LARGE NUMERALS) SOIL SYMBOLS
- A —— A COURSE OF SOIL BORINGS
- WATERSHED BOUNDARY (CONSTRUCTED)
- TERRACE RIDGE
- R-2 PRECIPITATION STATION AND NUMBER
- PREVAILING WINDS
- IMPEDING STRATUM
- WATERWAY

NOTE: ALL OTHER SYMBOLS THOSE ADOPTED AS STANDARD BY BOARD OF SURVEYS & MAPS

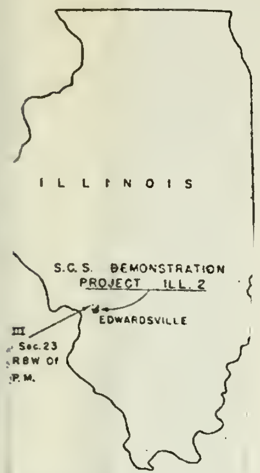
SCALE 1" = 100'

CONTOUR INTERVAL 1'

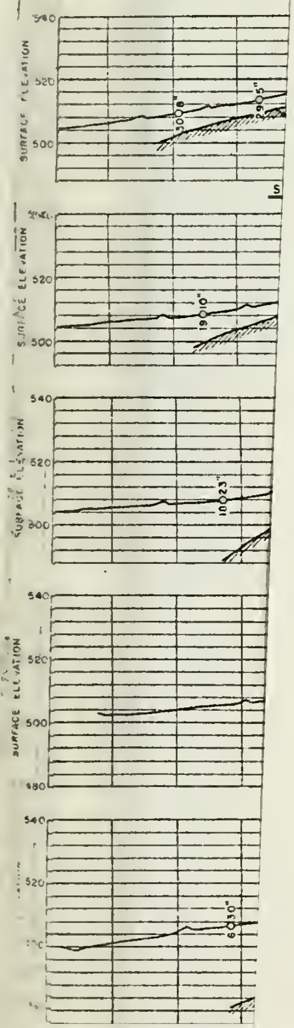
SOIL AND TOPOGRAPHIC MAP
WATERSHED W-II (STONE FARM)
PROJECT, OKLA-2 MUSKOGEE, OKLA.
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. BENNETT, CHIEF

REFERENCE: FIELD BOOK AND SOIL BORING NOTES	SURVEYED BY WESTBY & WHEATLEY	DATE
SUBMITTED:	APPROVED:	

PLOTTED	TRACED	CHECKED	DATE	DRAWING NUMBER
WESTBY	CURTIS	GRIFFIN	12-27-39	4-8-00-R3-0



LOCATION MAP



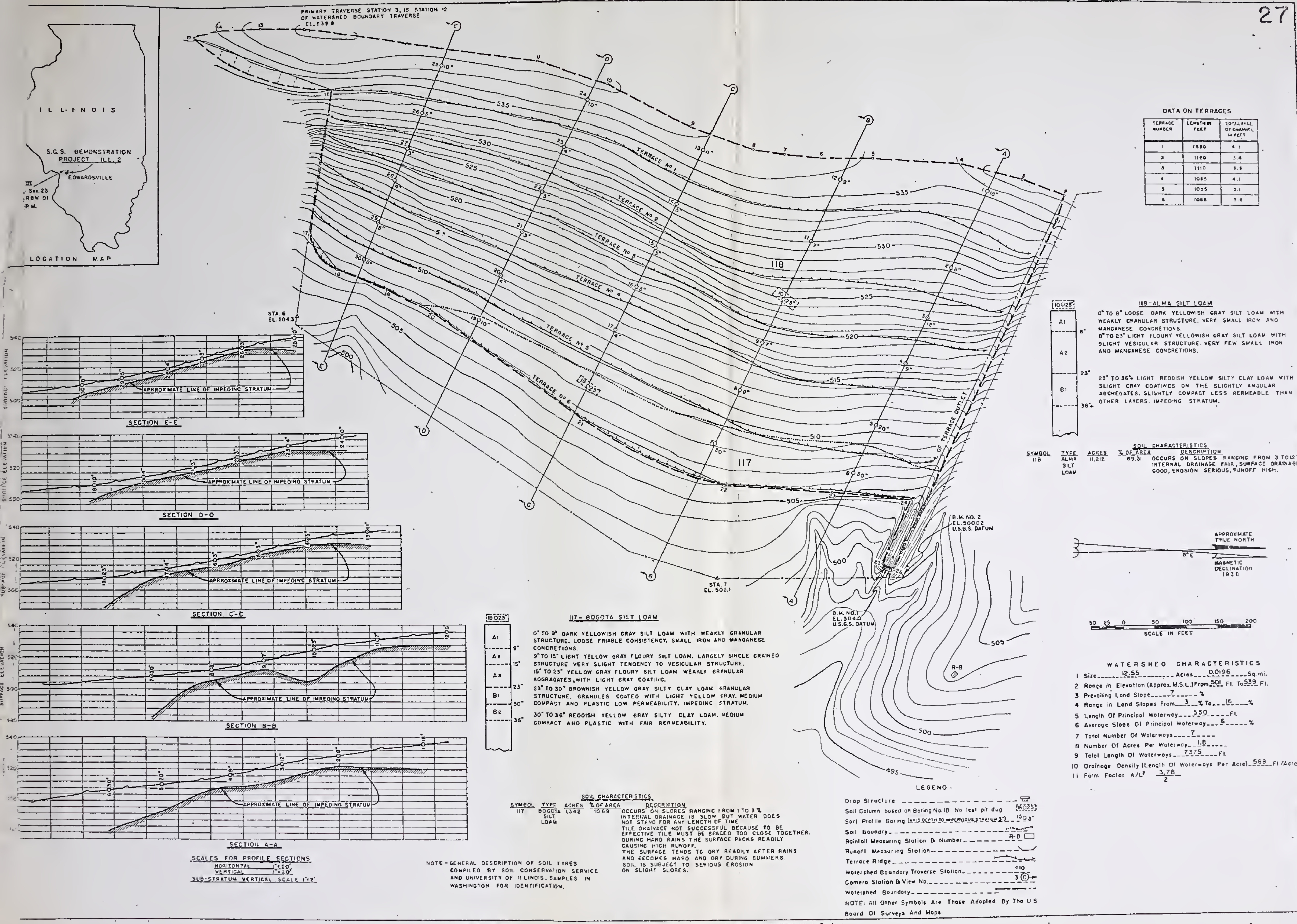


FIG. 6- SOIL AND TOPOGRAPHIC MAP WATERSHED W-III EDWARDSVILLE, ILL.